FIELD MODIFICATIONS OF A RECIRCULATING SAND FILTER TO INCORPORATE NITROGEN REMOVAL

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ABSTRACT

Recirculating Sand Filters (RSFs) are commonly used to treat septic tank effluent from individual homes and small communities. It is generally accepted that the RSFs can provide quality effluent with less than 10 mg/L of biochemical oxygen demand (BOD_5) and total suspended solids (TSS) concentrations. It is also accepted that the RSFs can provide partially nitrified effluent, with nitrogen removal efficiencies up to 40 percent. However, for applications such as schools and restaurants, where the influent total nitrogen concentrations can be as high as 70 to 80 mg/L, RSFs can fail to achieve sufficient nitrogen removal to comply with the permit requirements.

The RSF system that will be described in this paper is located in Chaparral, New Mexico. Chaparral is an unincorporated community in the southern New Mexico with a population of approximately 15,000. There are no centralized wastewater collection facilities in the Community to date. The RSF unit currently serves one elementary school and the middle school of the community. In this paper, the actual performance data of the treatment facility will be presented to evaluate the nitrification and denitrification capability of the plant since July 1998. After the installation of the RSF unit, the Biochemical Oxygen Demand (BOD_5) and Total Suspended Solids (TSS) removal efficiencies were about 98 and 90 percent, respectively. However, the nitrogen removal efficiency was sporadic, with an average of about 20 percent. In order to enhance nitrogen removal and to comply with the 27 mg/L effluent nitrogen requirements of the discharge permit, Bohannan Huston applied simple process modifications to the 25,000 gallon per day RSF treatment facility. The process modification included installation of a pump and a recycle line to return the nitrified RSF effluent to the septic tank. The described process modification is a low-cost and effective method of enhancing nitrogen removal, especially on existing systems without changing major design components of a treatment facility. With the improvement, the nitrogen removal efficiency observed at the plant increased to 54 percent.

KEYWORDS

Recirculating sand filters, nitrogen removal, on-site systems.

INTRODUCTION

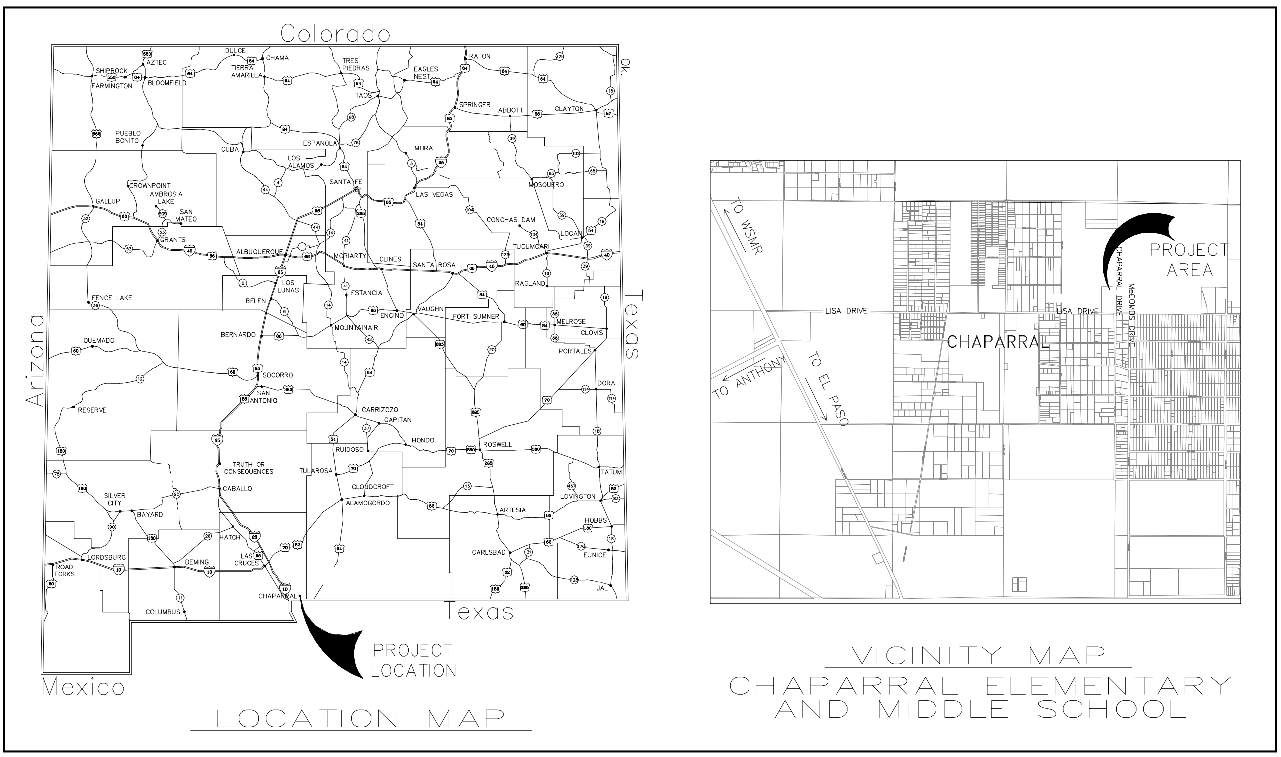
In this paper, an on-site wastewater treatment and disposal facility in Chaparral, New Mexico will be described. The treatment facility consists of a septic tank and a Recirculating Sand Filter (RSF) to treat wastewater generated from the two elementary schools and the middle school of the

community. This paper presents the original design of the RSF facility as well as the treatment efficiency achieved at the plant. The purposes of this paper are:

- To provide effluent wastewater characteristics from a septic tank (influent to RSF unit),
- To provide actual data on the treatment performance of RSF treatment systems,
- To present a simple process modification to an existing RSF system to increase the nitrogen removal efficiencies.

Description of the Community. Chaparral, New Mexico, USA, is located within 62 miles of the US/Mexico border in the southeastern portion of Doña Ana County, New Mexico, southwest of White Sands Missile Range and northwest of El Paso, Texas (see Figure 1). Chaparral is an unincorporated community with a population of approximately 15,000. The community is primarily rural residential with very little commercial or industrial land use. The area is semi arid with an average annual precipitation of 8 inches. Vegetation is sparse with the majority of soils having relatively slow percolation rates. The percolation tests performed during the initial phases of the project in 1991 indicated percolation rates of 8 to 12 minutes per inch. Depth of groundwater in the area is deep at 300 feet.

Figure 1 – Location and Vicinity Map



The water supply and distribution system is privately owned by the Chaparral Water System. The source of all water in the community is groundwater obtained from the Hueco Bolson aquifer. There are no central wastewater collection and treatment facilities available in the Chaparral. A Facility Plan has been developed for the community to provide centralized collection and treatment facilities. The estimated total cost is $34 million. No funds have yet been allocated to

the project. Currently, all residences, businesses and schools are on septic tank systems with leachfield effluent disposal.

There are three schools in the community, Chaparral Elementary, Desert Trail Intermediate and Chaparral Middle Schools. All three schools are operated and maintained by the Gadsden Independent School District (GISD).

Description of the Wastewater Treatment System of the Schools. The schools operate their own on-site wastewater treatment systems, which were originally comprised of septic tanks and leachfields. When the middle school septic system began to reach its capacity, the school district decided to not only increase the hydraulic capacity of the facility, but also wanted a system that can replace other septic tank/leachfields currently in use but may fail in the future. The facility was discharging its effluent via subsurface disposal under a groundwater discharge permit issued by the New Mexico Environment Department (NMED). The new groundwater discharge permit for the increased flowrates had a total nitrogen limitation of 27 mg/L.

Through their consulting engineer, the school district evaluated various options to provide on-site treatment facilities capable of meeting an effluent total nitrogen limit of 27 mg/L. The school district was not interested in operating a secondary treatment facility. While some activated sludge systems were evaluated, a septic tank coupled to a RSF unit was ultimately chosen. Seasonal temporary shut downs of the facility during summer months when school is not in session was one of the major considerations for the selection of the RSF system.

The school district worked with its consulting engineer and Orenco® Corporation to design and construct a RSF facility for the school. An ultimate flowrate of 50,000 gpd and a phased flowrate of 25,000 gpd were established to meet current and future flowrates from the schools. The wastewater treatment facility designed and constructed for Phase 1 consisted of the following units:

- 60 gallon per minute lift station/1000-feet force main
- one 35,000 gallon septic tank
- one 25,000 gallon recirculating effluent tank
- 5000 square feet sand filter
- 5 acre subsurface disposal leachfield
- miscellaneous valves, piping and appurtenance for collection piping

In this RSF facility, primary treatment occurs in the septic tank by allowing sufficient hydraulic retention time for settling and digestion of solids. Secondary treatment and partial nitrification/denitrification occurs when effluent flows from the septic tank by gravity to the recirculation tank. The recirculation tank contains small pumps that pump the effluent to the top of the sand filter where it percolates through the sand media to be treated by naturally occurring organisms. The treated effluent is collected in an underdrain system at the bottom of the sand filter and flows back to the recirculation tank to be either sent back through the filter or disposed of in the leach field. A simplified flow diagram of the facility is presented in Figure 2. Several photographs of the facility are provided in Figure 3.

Figure 2 – Simplified Flow Diagram of the Wastewater Treatment Facility

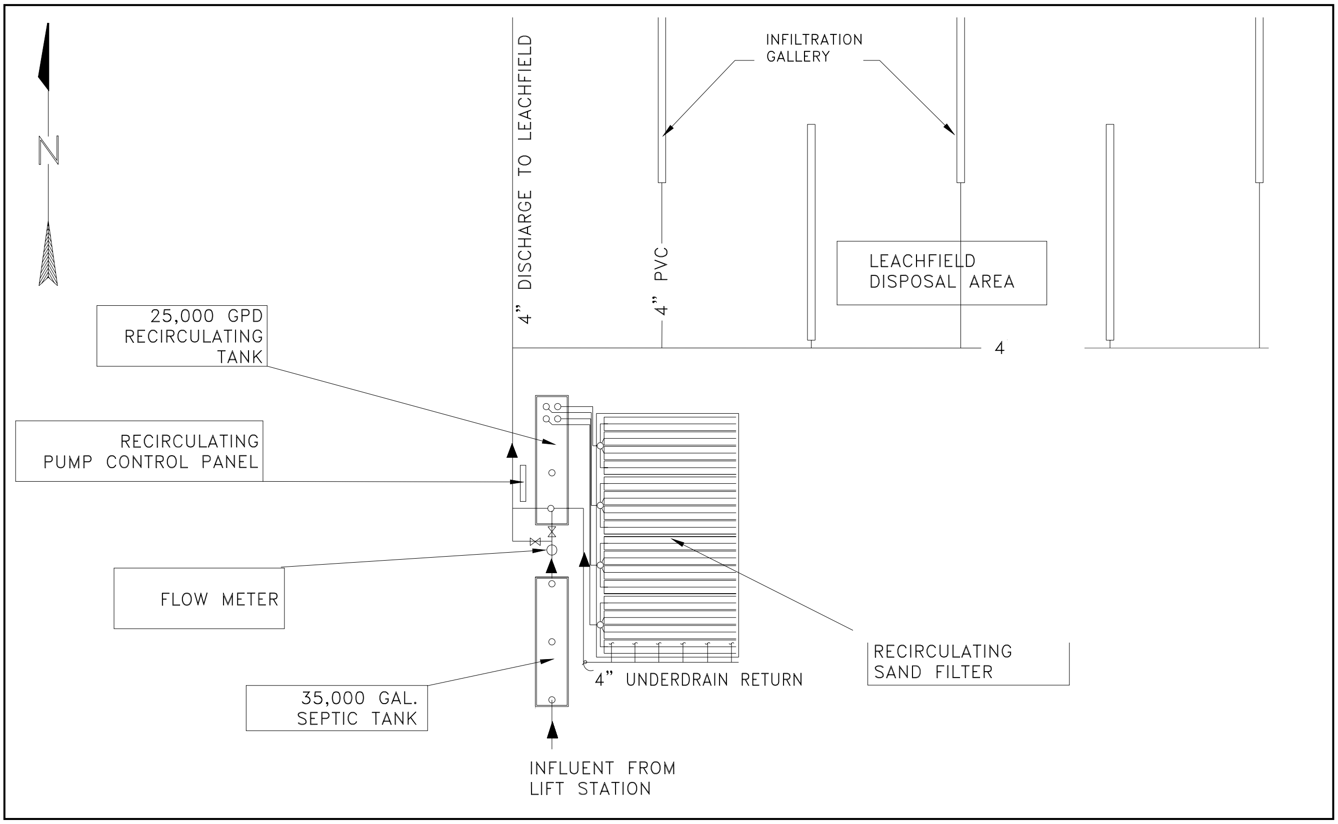
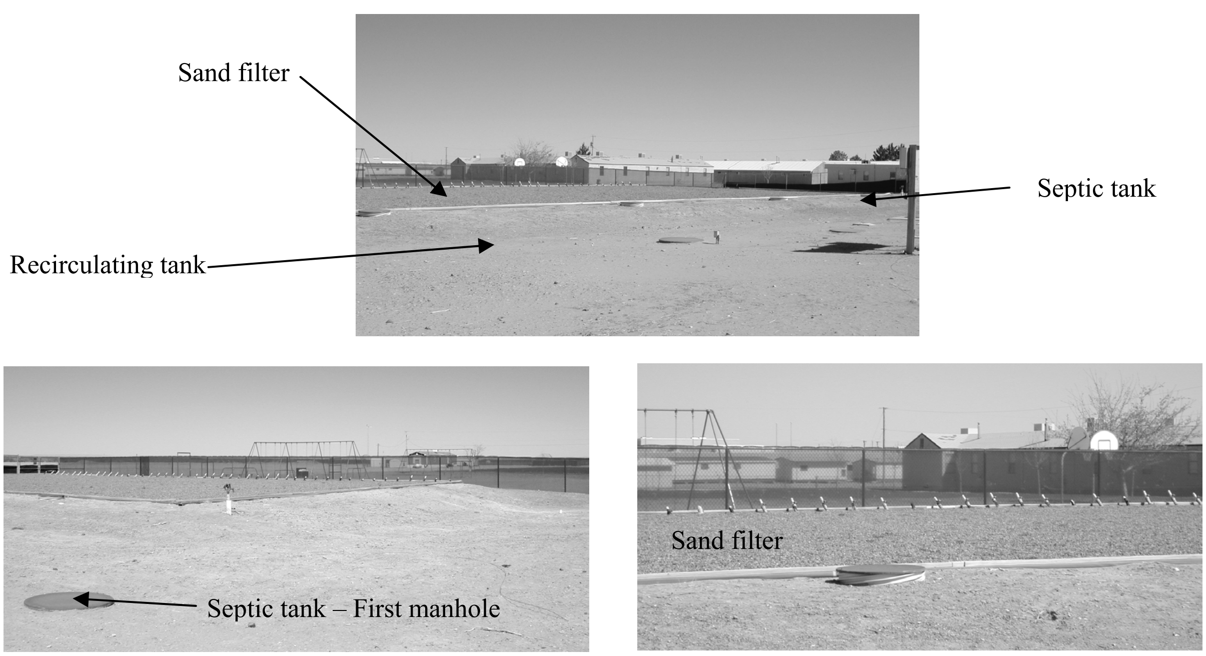


Figure 3 – Photographs of the RSF Treatment Facility



Total Construction Cost. The total construction cost of the treatment facility was $287,000 in 1998 for Phase 1 (25,000 gpd). This cost included the construction of the following units:

- 60 gallon per minute lift station/1000-feet force main
- one 35,000 gallon septic tank
- one 25,000 gallon recirculating effluent tank
- 5000 square feet sand filter
- 5 acre subsurface disposal leachfield
- miscellaneous valves, piping and appurtenance for collection piping

Regulatory Requirements. Discharge of the treated effluent to a receiving stream was not possible for the project. Disposal by land application or irrigation/reuse were the applicable effluent disposal scenarios. Since the communities in New Mexico rely on groundwater as their sole source of water, such on-site effluent disposal methods are strictly regulated in terms of their nitrogen content. The effluent nitrogen limitations that were and are currently in effect in New Mexico for facilities achieving effluent disposal through leachfield or land application, are summarized in Table 1. These regulations are implemented by NMED and require a groundwater Discharge Permit (DP).

Table 1 – Effluent Disposal Regulatory Requirements with respect to Nitrogen

Parameter Description	Regulatory Requirement	Design Requirement to Achieve Compliance
Nitrate nitrogen limit	<10 mg/L	denitrification
Nitrogen loading limit	<200 lbs/acre/year	10 acres for 55,000 gpd flow

NMED evaluates the wastewater facilities in the State on a case-by-case basis and determines the effluent nitrate-nitrate limit to be implemented. For the school district RSF facility, a maximum of 27 mg/L nitrate-nitrogen was permitted.

Original Design Details of the RSF Wastewater Facility. The existing and projected student populations were used as the design basis in determining the wastewater design flowrates for the facility. At the time of design of the facility (in 1997), limited data on the actual wastewater generation rates indicated an average of 10 to 15 gpm (14,400 gpd) with a 1-hour peak flow of approximately 120 gpm occurring on the first day of every school week, and 1 to 2 hour peak flow of approximately 60 gpm during the rest of the week. These metered flowrates during the peak hours are higher than the typical flowrates, but are consistent with the averages reported by Metcalf and Eddy (1991).

Considering the limited amount of actual flowrate data as well as the typical wastewater generation rates reported in the literature, an average wastewater generation rate of 25 gallons per capita per day (gpcd) was used for the Middle School with cafeterias and a gym. The wastewater generation from the elementary school was anticipated at 15 gpcd since the elementary school included cafeterias but no gyms. The wastewater flowrates used in the original design are summarized in Table 2. The project was phased into two terms and the first phase of 25,000 gpd treatment capacity was constructed in 1998.

Table 2 – Population and Wastewater Design Flowrates for the Chaparral Schools

Design Data	Middle School	Elementary School
1996/1997 student population	450	1,600
Projected student population	1,000	2,000
Estimated 1996/1997 wastewater flowrate (gpd)	11,250	24,000
Anticipated per capita wastewater generation rates (gpcd)	25	15
Anticipated projected wastewater flowrates (gpd)	25,000	30,000
TOTAL WASTEWATER FLOWRATE (gpd)	55,000	
PHASE 1 WASTEWATER FLOWRATE (gpd)	25,000	

Similar to the case of the wastewater flowrates, actual data on the influent wastewater or septic tank effluent quality were not available. Therefore, in the design of the RSF unit, typical wastewater characteristics reported for septic tank effluents were used. The criteria used in the design are summarized in Table 3 (Metcalf and Eddy, 1991).

Table 3 – Septic Tank Effluent Wastewater Design Criteria

Design Data	Typical Range	Design Value
5-day Biochemical Oxygen Demand (BOD_5)	140 – 200	175
Total Suspended Solids (TSS)	50 – 90	75
Total Kjeldahl Nitrogen (TKN)	25 - 60	50

Design Details of the Effluent Disposal Facility. The existing 90,000 square feet (1.72 acres) of leachfield area was not large enough to comply with the NMED Regulations and the new discharge permit requirements of 27 mg/L nitrogen. Based on a 50 percent reduction of nitrogen, from 50 mg/L to 25 mg/L, at a flow of 55,000 gpd, ten acres of leach field will be required. In Phase 1, only half of this area (5 acres) was built and is currently in operation.

BACKGROUND INFORMATION ON RECIRCULATING SAND FILTERS

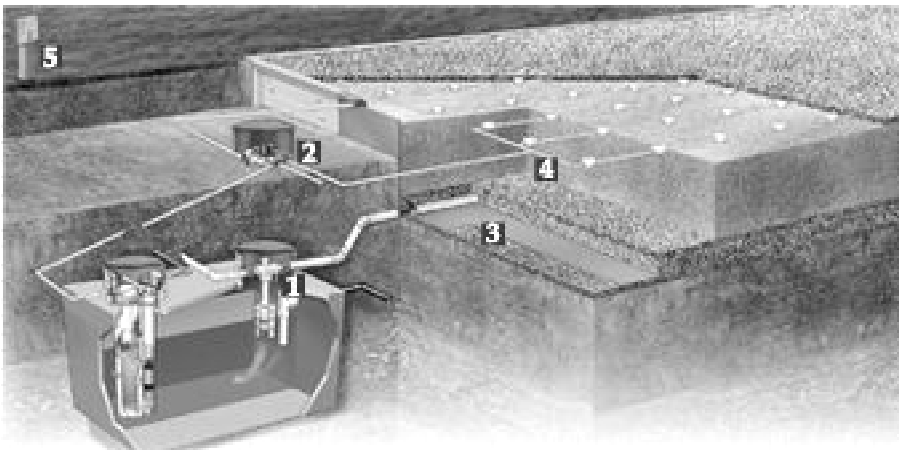
RSFs are commonly used to treat septic tank effluent from individual homes and small communities. It is generally accepted that the RSFs can provide quality effluent with less than 10 mg/L of BOD_5 and TSS concentrations. It is usually accepted that the RSFs can provide partially nitrified effluent, with typical nitrogen removal efficiencies of 40 to 50 percent (Crites and Tchobanoglous, 1998). Recirculating filters achieving as high as 82 percent nitrogen removal have been reported (Crites and Tchobanoglous, 1998).

Several manufacturers developed proprietary systems to provide additional nitrogen removal in RSF systems. One of these systems includes installation of an attached growth reactor above the septic tank unit to incorporate denitrification. Another system involves separation of gray water from black water to achieve about 80 percent nitrogen removal by providing treatment via two

separate septic tank systems. In another alternative, septic tank effluent is diverted to a rock storage filter, which promotes denitrification.

Information on Orenco® RSF Systems. For the school district RSF facility, the RSF unit provided by Orenco® Systems was selected, considering a number of factors including capital costs and anticipated nitrogen removal efficiency. A typical depiction of the Orenco® RSF Systems is presented in Figure 4, and the components of this system are briefly described below (Orenco® Systems web page, 2002).

Figure 4 – Typical Components of an Orenco® RSF Facility*



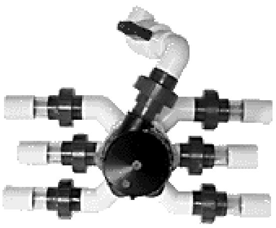
* 1: Recirculating splitter valve; 2: Distributing valve assembly; 3: Liner, 4: Manifold kit; 5: Control panel.

Recirculating splitter valve. These valves provide the required flow-split in the facility. Constructed of a PVC enclosure and ball float, the valves redirect 100 percent of the incoming flow to the recirculation tank during periods in which the ball is not seated and 80 percent or less when the ball is seated. They can be field-adjusted for splits ranging from “no split” (as with recirculating ball valves) to a 4:1 split. The desired recirculation ratio will be achieved even during peak flows. A depiction of the valve is presented in Figure 5.

Figure 5 – Recirculating Splitter Valves by Orenco® Systems

Distributing valve assembly. These valves are mechanically operated and sequentially redirect pump flow to multiple zones or cells in the sand filter. The valve is actuated by pressure and flow. A depiction of the valve assembly is presented in Figure 6.

Figure 6 – Distributing Valve Assembly by Orenco® Systems



Liner. The sand filter liners of the RSF unit contain sand filter media and effluent within the walls of a sand filter. Constructed of 30-mil PVC vinyl, liner material is UV resistant for extended life and performance.

Manifold kit. Included in the sand filter manifolds are the manifold, lateral piping, orifice shields, collection underdrain, and flushing assemblies with access ports, ready to install in the sand filter bed. The manifold kit is used to ensure accurately sized and spaced orifices. A depiction of the manifolds is presented in Figure 7.

Figure 7 – Manifold Kit by Orenco® Systems

Control panel. Control panels for RSFs include remote telemetry to monitor system performance. Remote telemetry units collect and record data, notify operators of alarm conditions, and control system functions. They allow timed-dosing, and they also include current sensors for immediate detection of pump problems. No special software is required (see Figure 8).

Figure 8 – Control Panel by Orenco® Systems

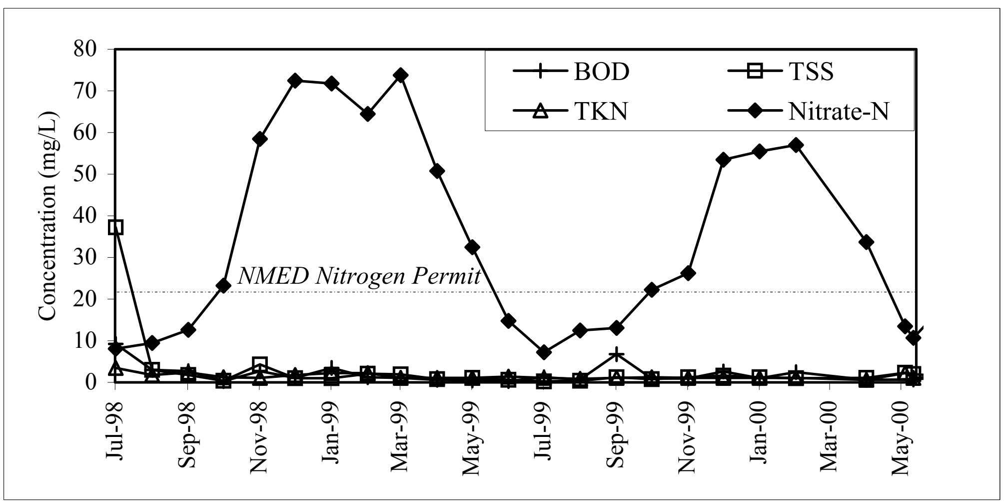
ORIGINAL RSF PERFORMANCE AND DESCRIPTION OF THE PROBLEM

The RSF facility as described above was constructed and brought on line in July 1998 and Bohannan Huston Inc. has been monitoring the influent (effluent from septic tank) and effluent quality data for the RSF unit since then.

BOD_5 and TSS Treatment Efficiency. Even though the influent BOD_5 levels showed large fluctuations, the RSF facility achieved about 98 percent BOD_5 removal. The facility produced an effluent wastewater with 2 mg/L of BOD_5 and 3 mg/L of TSS concentrations as monthly averages. The effluent BOD_5 and TSS concentrations are plotted in Figure 9.

Nitrogen Treatment Efficiency. During the winter months, the influent nitrogen concentrations were significantly higher than the anticipated value of 50 mg/L. As a consequence, the efficiency of the treatment facility was sporadic. The total nitrogen levels in the plant effluent were above the NMED permit limit of 27 mg/L. The total nitrogen removal efficiency observed at the plant was 20 percent, with an average effluent nitrate-nitrogen concentration of 37 mg/L. The effluent nitrogen concentrations during the initial two years of operation are plotted in Figure 9.

Figure 9 – Effluent Wastewater Quality After the Construction of the RSF Unit



As can be seen in Figure 9, the effluent nitrate-nitrogen concentrations followed a cyclic pattern. This cyclic pattern was similar to the cyclic pattern observed with the influent flowrates to the treatment facility. When the school is in operation, as a result of increased flowrates and increased influent TKN concentrations, the effluent nitrate nitrogen concentrations were also high. This relationship between the influent TKN values and effluent nitrate-nitrogen levels are depicted in Figure 10.

Unfortunately, monthly flowrate measurements are not available to further explore the relationship between the influent flowrates and effluent nitrogen values. However, the wastewater flowrates into the treatment facility were estimated using the water usage data obtained from the State Engineer's Office. The water use and estimated wastewater flowrates are presented in Table 4.

Figure 10 – Relationship Between The Influent TKN And Effluent Nitrate-Nitrogen Levels

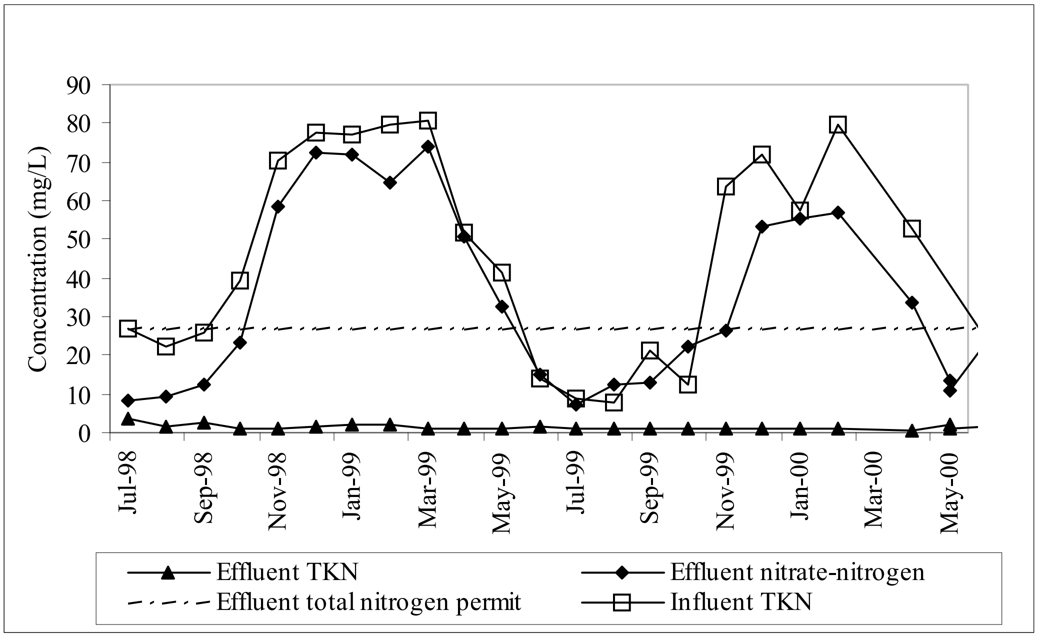


Table 4 – Water Use and Estimated Wastewater Flowrates

Month	Water Use	Estimated Wastewater Flowrate*
September 2001	288,660 gal/month	10,691 gpd
October 2001	260,500 gal/month	6,326 gpd
November 2001	227,600 gal/month	6,450 gpd

* Wastewater generation is estimated to be 85 percent of water use.

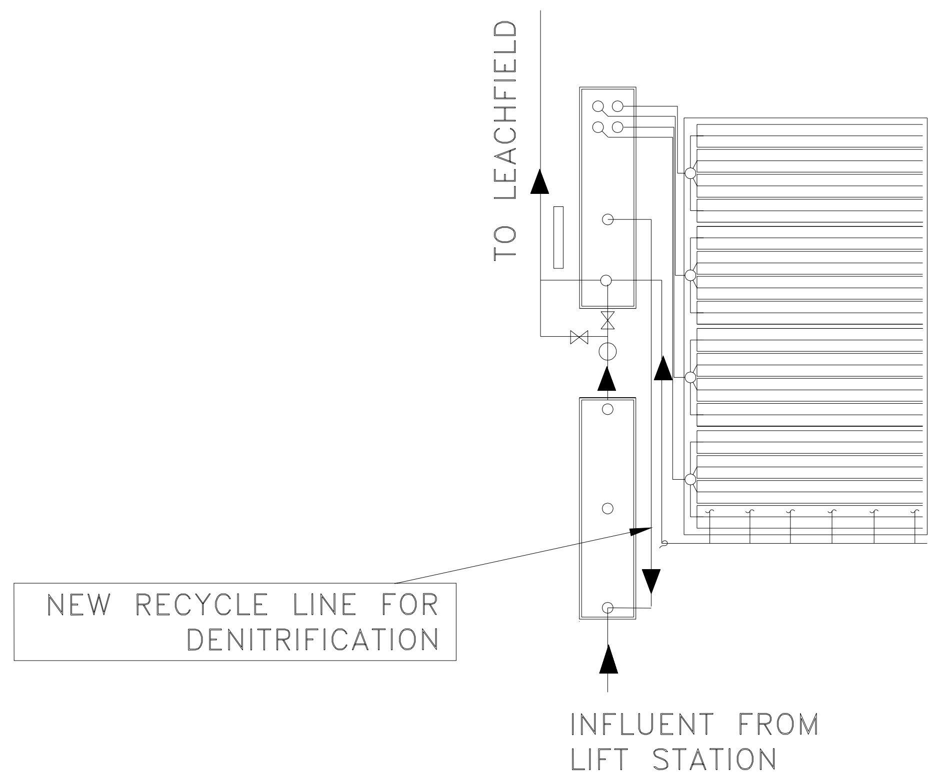
SOLUTION METHODOLOGY

In order to comply with the nitrogen requirements of the discharge permit, Bohannan Huston, Inc. analyzed the collected data to evaluate alternatives in order to enhance nitrogen removal in the facility. As indicated with the high nitrate-nitrogen concentrations in Figure 10, the treatment facility successfully nitrified the wastewater, but was not sufficient in denitrification. Since anaerobic conditions are required for adequate denitrification, Bohannan Huston, Inc. evaluated ways to incorporate anaerobic conditions. It was postulated that the influent septic tank would be ideal in creating anaerobic conditions, and hence promoting denitrification of wastewater, if nitrified effluent, which is rich in nitrates, were recycled back to the septic tank.

For this purpose, Bohannan Huston, Inc. modified the process to include a pump and a recycle line to recycle a portion of the nitrate-rich effluent from the recirculation tank to the anaerobic septic

tank to promote denitrification. About 100-ft of PVC pipe and a submersible pump were installed to recycle 100 percent of the nitrified effluent on a 12-hour cycle. The schematic of the modifications is depicted in Figure 11. The recycle pump was placed in the recirculation tank. The 100-ft long recycle line was installed between the pump and the septic tank. The recycle line into the septic tank was extended to the 6-inches below the water surface. However, this setup created a solids wash-out problem, as will be discussed in the following pages. The total construction cost of these modifications was about $500 in 2000 prices.

Figure 11. Schematic of the Modifications to the RSF Facility



RESULTS ACHIEVED AFTER MODIFICATIONS

The modifications depicted in Figure 11 were implemented in May 2000. The influent and effluent nitrogen concentrations observed at the treatment facility before and after the modifications are plotted in Figure 12. As can be seen in Figure 12, after the installation of the pump to recycle the treated effluent back to the septic tank, the effluent nitrate-nitrogen concentrations showed a slight decline, and increased above the permit requirements afterwards. Around the same period, in January and February 2001, the first school season after the installation of the recycle pump, the effluent BOD_5 and TSS concentrations increased significantly (see Figure 13). The maximum effluent BOD_5 and TSS concentrations observed at the plant effluent were as high as 97 and 29 mg/L, respectively.

Figure 12. Influent and Effluent Nitrogen Concentrations After the Modifications

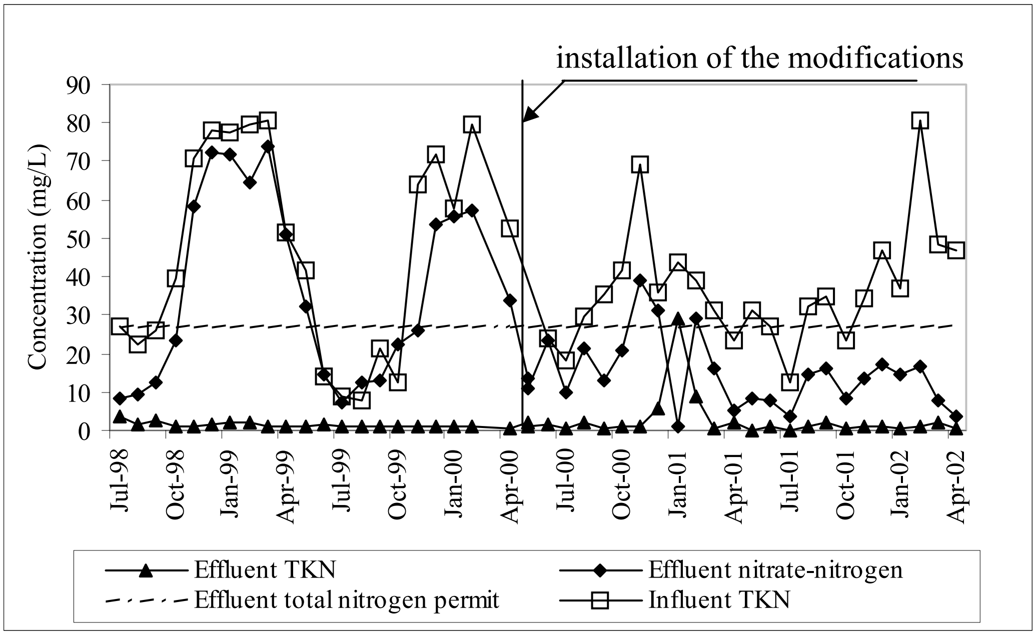
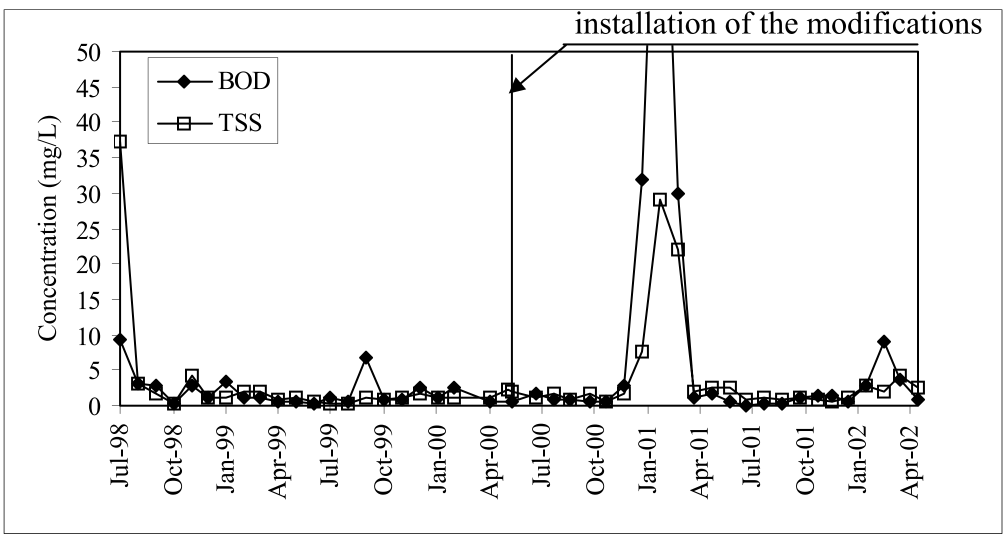


Figure 13. Influent and Effluent BOD_5 and TSS Concentrations After the Modifications*



* The effluent BOD data for January 2001 was not plotted for clarity of the other plotted data. The numerical value of the unplotted data for January 2001 is 97 mg/L.

The site visits to the plant during this period revealed that the septic tank, the recirculation tank, and the sand filter were significantly plugged with solids and all the components of the treatment facility required cleaning. We concluded that this solids wash-out occurred due to the recycle line

stirring up the settled solids in the septic tank since the recycle pump was set to run continuously. As a solution, the timer was re-set to run only for 12 hours a day since the hydraulic detention time of the septic tank was 24 hours. The recycle pump was set to turn off during the day when the wastewater from the school continues to flow into the treatment system. During the night hours, when the flowrate into the facility is low, the recycle pump was set to turn on and pump the nitrified effluent into the septic tank for denitrification. This arrangement was intended to provide 12-hours of quiescent conditions for adequate solids settling and 12-hours of nitrified effluent inflow for denitrification. It was also hypothesized that recycling the nitrified effluent during the night hours will help equalize the flowrate through the system and will help increase the overall treatment efficiency. In addition, the recycle line into the septic tank was extended to the bottom of the septic tank in order to promote the release of nitrate-rich wastewater into the center of the anaerobic bacterial culture.

After the implementation of the 12-hour setting of the pump, the data collected during the last school season indicates that the nitrogen removal efficiency of the treatment facility is satisfactory. The total nitrogen removal efficiency of the facility increased to 54 percent and the average effluent nitrate-nitrogen concentrations dropped to 15 mg/L. Even with influent TKN concentrations as high as 80 mg/L, the modified system has been nitrifying and denitrifying sufficiently. During the last season, high influent TKN concentrations in the order of 70-80 mg/L were observed only during February 2002. For this month, the effluent total nitrogen concentration of the plant was about 18 mg/L (17 mg/L nitrate-nitrogen and 1 mg/L TKN). No other operational or process related problems were reported since the last solids wash-out incident in February 2001. The effluent BOD_5, TSS, and nitrogen concentrations observed at the facility are summarized in Table 5.

Influent and Effluent Wastewater Alkalinity. In general, the groundwater in New Mexico is hard with high alkalinity levels. For the RSF facility described in this paper, the alkalinity of the influent and effluent wastewater was measured only for two sampling periods (December 2001 and January 2002) as a control parameter. The data indicated that the influent wastewater has an average alkalinity of 263 mg/L, and the treated wastewater has an average alkalinity of 120 mg/L. As such, upset of the septic tank due to decrease of alkalinity and increase of pH is not expected, and the data collected during the last school season are in agreement with this conclusion.

FUTURE DEVELOPMENTS

During the last season, the GISD was interested expanding their treatment facility and funds were available to upgrade the system. For this purpose, a second 35,000 gal septic tank was designed. The septic tank is currently under construction.

The new septic tank will increase the hydraulic capacity of the facility and primary treatment efficiency. The new septic tank will operate in parallel with the existing septic tank and will increase the available anaerobic volume in the facility. In theory, increasing the available anaerobic volume will allow more nitrified RSF effluent to be recycled into the septic tank while keeping the 12-hour settling/denitrification cycle. We believe that recycling a larger volume of nitrate-rich RSF effluent into the septic tank will increase the overall nitrogen removal of the

facility. If this is achieved, then constructing additional disposal fields may not be necessary for the ultimate flow rate.

Table 5. Effluent Wastewater Quality Before and After the Modifications

INFLUENT QUALITY		
Parameter	Average Concentration Before May 2000	Average Concentration After May 2000
BOD_5	105	108
TSS	30	67
TKN	47	37
Nitrate nitrogen	1	1
EFFLUENT QUALITY		
Parameter	Average Concentration Before May 2000	Average Concentration After May 2000
BOD_5	2	8
TSS	3	4
TKN	1	3
Nitrate nitrogen	37	15
Total dissolved solids	680	652
TREATMENT EFFICIENCIES		
Parameter	Average Efficiencies Before May 2000	Average Efficiencies After May 2000
BOD_5	98	93
TSS	90	94
Total nitrogen	20	54

CONCLUSIONS

The RSF treatment facility constructed for the Gadsden Independent School District in Chaparral, New Mexico, was not capable of achieving adequate nitrogen removal to comply with the State Discharge Permit requirement of 27 mg/L of total nitrogen. The nitrogen removal efficiencies observed at the plant was about 20 percent, with an average effluent total nitrogen concentration of about 37 mg/L. The high nitrate-nitrogen concentrations in the sand filter effluent indicated that the plant was sufficiently nitrifying, but denitrification was limited. It should be noted that during the school year, the influent TKN concentrations to the plant were high at about 70 to 80 mg/L.

In order to enhance denitrification, a recycle line was installed to return 100 percent of the treated effluent to the septic tank for 12-hours per day. The nitrogen removal efficiencies after this modification increased to 54 percent, resulting in an average total nitrogen concentration of 15 mg/L in the effluent. Even with influent TKN concentrations as high as 80 mg/L, the system have been nitrifying and denitrifying sufficiently, and producing effluent total nitrogen concentrations below the permit requirements.

The 2.7 fold increase in nitrogen removal efficiencies were accomplished by a total construction cost of about $500 in 2000 prices. The BOD_5 and TSS removal efficiencies observed at the facility were sufficient before and after the modifications.

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REFERENCES

Metcalf and Eddy (1991). *Wastewater Engineering: Treatment, Disposal and Reuse*, 3rd edition, Tchobanoglous, G., Burton, F.L., McGraw-Hill, Inc. New York, NY.

Crites, R. and Tchobanoglous, G. (1998). *Small and Decentralized Wastewater Management Systems*, McGraw-Hill, Inc., Boston, NY.

Orenco web site, 2002. http://www.biotube.com/ots/ots_rsf_index.asp)